**EE 488 Power Systems Analysis I – Problem Set #1 - solutions**

**Assignment:**

1. (25 pts) A single-phase, 416Vrms source is supplying power to five loads, on a small factory floor, that are connected in parallel. All loads operate at 416V, single phase, and 60 Hz:

* An induction motor drawing 40 kW real power and 25 kVAR reactive power
* A synchronous motor with output of 30 HP, at 80% efficiency and 0.95 pf leading (remember to convert HP to real power in kW)
* A single-phase transformer drawing a primary current of 52 ∠ -25° A
* A bank of electronic ballast, fluorescent lights drawing 22 kW of real power at a power factor of 0.96 lagging
* Miscellaneous other equipment loads that when combined have an apparent power of 12 kVA at a power angle of 20°

Do the following:

1. (15 pts – 3 pts each load) Draw individual power triangles for each load; be sure everything is labeled, including real, reactive, & apparent powers, power angles, and axes. Be sure to show all work resolving each of the loads into rectangular and/or polar coordinates. You may round all values to 2 places to the right of the decimal.

**Load 1:**

A red triangle with numbers and a red line

Description automatically generated

**Load 2:**

A red lines with numbers and a red line

Description automatically generated

**Load 3:**

A red triangle with numbers and a straight line

Description automatically generated

**Load 4:**

A red triangle with numbers and a red line

Description automatically generated

**Load 5:**

A red line with numbers and a red line

Description automatically generated

1. (4 pts) Determine the real, reactive, and apparent power delivered by the source to the combined load, as well as the power factor for the combined load. You may round all results to 2 places right of the decimal.
2. (3 pts) Draw a power triangle for the combined load – be sure everything is labeled, including real, reactive, & apparent powers, power angle, and axes.

A red and blue triangle with numbers and a red line

Description automatically generated

1. (3 pts) Determine the magnitude of the total current flowing from the source to the combined load
2. (25 pts – includes 5 pts for finding actual, final power factor) You are designing power factor correction for a 416V, single-phase, load operating at 60 Hz. The load draws 500 kVA at 0.75 lagging. It is desired to correct the load to a power factor of 0.96 lagging or higher. The pf capacitive bank comprises a large number of identical 0.25 mF capacitors that can be switched in parallel with the load. How many caps (integer number) will have to be switched in with the load in order to meet the power factor requirement? Be sure to show all of your work. Once the appropriate number of caps are switched in, what is the final, actual power factor seen at the load (compute to 3 decimal places)?
3. (25 pts – includes 5 points for proper final form) Shown here is the circuit of a simple, four-node power grid that operates at 60 Hz. The voltage sources have already been transformed to current sources. All impedances are in Ohms. Nodes are numbered in red as shown.

A diagram of a circuit

Description automatically generated

Find the 4x4 bus admittance matrix, Ybus, for this system and then write the nodal equations in matrix/vector format. **You do not have to solve the equations**. Also, when writing the current vector, express the currents in phasor notation (polar form).

1. (25 pts) A three-phase, Y-connected, 60 Hz source is connected to a pair of balanced three-phase loads via a three-phase line in which each line has a series impedance of 2 + j8 Ω. The three-phase loads are delta connected with each phase in parallel. The characteristics of the loads are:
   * Load 1 is an inductive 3φ load absorbing 750 kVA (total) at 0.6 pf lagging
   * Load 2 is a 3φ lighting load absorbing 540 kW (total) at unity pf
   * At the load end, the line-to-line voltage is 8.66 kV

Do the following (be sure to show proper units for every quantity, as appropriate. Also, round quantities to 2-3 places to the right of the decimal point, as appropriate):

* 1. (5 pts) Draw a single-phase, line-to-neutral, equivalent of one phase of the system;

Be sure to show all calculations leading to this diagram.

A red rectangular object with numbers and symbols

Description automatically generated

* 1. (3 pts) Find the magnitude of the line current in one line
  2. (4 pts) Continuing with one line, assume a reference of zero phase on the load voltage and compute the line-to-neutral and the line-to-line voltage at the source end. Show as phasor quantities in polar form. Hint: don’t forget that line current, as a complex quantity, is in the opposite quadrant from load power (if load power is in the 1st quadrant, then current is in the 4th, and vice versa).
  3. (3 pts) Use the magnitude of the line current to compute the real and reactive power losses in one line. Show your answer in both polar and rectangular coordinates.
  4. (3 pts) Compute the total three phase power required at the source in rectangular coordinates. Hint: when you are computing the single phase power at the source, don’t forget that you can do a power check to verify your numbers.
  5. (4 pts) Design a delta-connected capacitor bank for a pf correction to unity for the combined load. What is the value of the capacitive reactance and the actual capacitance value for each leg of the pf correction? Be sure to use correct units.
  6. (3 pts) After power factor correction, what is the magnitude of the new line current in one line from the source? Recompute the complex power loss in each line in rectangular coordinates (similar to step d.). What is the percentage improvement in real power lost in each line compared to the system without power factor correction?

**Extra Credit.** (5 pts)Power companies calculate the cost of providing power based on three-phase, apparent power at the generator. Suppose it costs the company $25 per MVA-hour to produce the power. Calculate the dollar savings at the source end achieved by using power factor correction (corrected to unity pf) in this scenario, versus not using it at all, for one year of operation.

Savings for one year are: 277.47k – 223.6k = $53,870.

Load 1:

**25**

**47.17 kVA**

**32°**

**40**

**P [kW]**

Load 2:

**27.96**

**P [kW]**

**-18.19°**

**29.43 kVA**

**-9.19**

**Q [kVAR]**

Load 3:

**Q [kVAR]**

A red line with a straight line

Description automatically generated

**25°**

**9.14**

**19.6**

**21.63 kVA**

**P [kW]**

Load 4:

**Q [kVAR]**

A red line with a straight line

Description automatically generated

**22.92 kVA**

**16.26°**

**22**

**6.42**

**P [kW]**

Load 5:

**Q [kVAR]**

A red line with a straight line

Description automatically generated

**4.1**

**11.28**

**20°**

**12 kVA**

**P [kW]**

Combined Load:

**Q [kVAR]**

A red line with a straight line

Description automatically generated

**16.26°**

**125.94 kVA**

**120.84**

**35.47**

**P [kW]**